NEWS! From the NAVAL OBSERVATORY

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U.S. Naval Observatory
Press Release

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FOR IMMEDIATE RELEASE

NEED TO FIND DIRECTIONS TO MARS? ASK A QUASAR!

What does measuring the positions of distant quasars have to do with landing robots on Mars? If you are aiming $800 million worth of hardware at a 1-kilometer (0.6-mile) wide corridor through the tenuous outer fringes of the Martian atmosphere, the answer is "Everything!"

When the Mars Exploration Rovers "Spirit" and "Opportunity" departed planet Earth in the fall of 2003 they began a journey that would deliver them from the shores of Florida to a point in space some half a billion kilometers (300 million miles) away, where the planet Mars would essentially overtake them in a kind of controlled "cosmic traffic accident". When these "collisions" took place in January 2004 each MER spacecraft was within 200 meters (660 feet) of its "perfect" aim point.

The key to the resounding success of both missions was the knowledge of the precise locations of the spacecraft, Mars, Earth, and especially the tracking antennas of NASA's Deep Space Network throughout the MERs' flights. The U.S. Naval Observatory's Earth Orientation Department played a critical role in providing that knowledge.

Traveling almost anywhere raises a fundamental problem: in order to determine where you are going, you first have to know where you *are*, and in order to know where you *are*, you need to have a frame of reference. For centuries, ocean navigators used the stars as a reference frame to determine positions at sea. As we now venture out into interplanetary space, we still use celestial objects for reference, but the stars can no longer provide the precision we need to hit a small target on another planet.

The simple fact is that the stars move. Our Sun is one star among hundreds of billions in a great, majestically spinning galaxy. Attended by its family of planets, the Sun bobs and weaves its way around the galaxy once every 200 million years, as do all the stars that are nearby. The familiar constellations of tonight's sky will be completely distorted about 100 thousand years from now by these random and regular stellar motions. Basing a reference frame on moving targets means that every 50 years or so the reference stars and all the objects that relate to them must have their positions re-computed, an enormous task given the number of catalogued objects in the Universe.

The solution to this dilemma is to find a reference frame that does not move. Fortunately, Nature has given us the perfect objects to meet this need: quasars. Quasars were once very abundant when the Universe was very young. They are believed to have been enormous "black holes" in the centers of the first galaxies to form after the Big Bang. They are so far away that their high-energy X-ray and Gamma-Ray emissions have been shifted into the low-energy microwave portion of the electromagnetic spectrum, and their distances are thus measured in tens of billions of light years!

By arraying together individual, sensitive radio telescopes, typically separated by thousands of kilometers, and simultaneously observing individual quasars, astronomers can create a "grid" of these distant objects that can then serve as the fundamental reference frame of the Universe. The technique of combining remote radio telescopes is called "Very Long Baseline Interferometry", or VLBI. The combination of data from the VLBI network is accomplished at the USNO's Mark-V Correlator Facility in Washington, DC. The reduced data not only determine the precise place of a quasar source, they also tell us the precise orientation of the planet's rotational pole at the time of the observation. The reference grid of quasars is known as the International Celestial Reference Frame (ICRF). When combined with data obtained from other sources, such as the constellation of Global Positioning System satellites and laser-ranging of geodetic satellites and the Moon, USNO Earth Orientation Department astronomers can also determine exactly how rapidly the Earth is spinning relative to the ICRF.

How does this help spacecraft to get to Mars? Interplanetary probes are in constant touch with the Earth through the NASA Deep-Space Network (DSN), a trio of tracking facilities each spaced roughly one-third of the way around the world. By observing a spacecraft's radio beacon with two instruments simultaneously, NASA trackers can use VLBI correlation to pinpoint the probe's position relative to the ICRF, and the tiny Doppler shifts in the beacon's carrier frequency can be measured to determine the spacecraft's speed relative to the Earth.

However, even tiny variations in the velocity of the Earth's rotation and the orientation of its rotational pole can introduce a significant uncertainty into the exact positions of the tracking antennas relative to the spacecraft, and so must be factored out in order to yield the most accurate positions and velocities. The USNO's Earth Orientation Department provided near-real time data to JPL navigators on a daily basis as the critical encounter dates drew near.

According to a recent story on JPL's Mars Exploration Rover website, the exact location of each of the DSN tracking antennas must be known to a precision of better than 5 centimeters (2 inches) on the surface of the Earth. Any uncertainty in position greater than this can build over the current distance between Earth and Mars, leading to a 0.5-kilometer (1500-foot) location error at the red planet. Hitting a precise landing site target that is scientifically interesting on Mars is thus nearly impossible unless the Earth's current rotation rate is known to the timing of better than two ten-thousandths of a second!

So the next time you need to know exactly where you are in the solar system, look no further than the U.S. Naval Observatory. We'll help you find your way out and back again.